Bacteriology of War Wounds at the Time of Injury

Guarantor: MAJ Clinton K. Murray, MC USA
Contributors: MAJ Clinton K. Murray, MC USA*; MAJ Stuart A. Roop, MC USA†; LTC(P) Duane R. Hospenthal, MC USA*; COL David P. Dooley, MC USA*; CPT Kimberly Wenner, MC USA‡; MAJ John Hammock, MC USA‡; CPT Neil Taufen, MC USA‡; MAJ Emmett Gourdine, MS USA‡

Bacterial contamination of war wounds occurs either at the time of injury or during the course of therapy. Characterization of the bacteria recovered at the time of initial trauma could influence the selection of empiric antimicrobial agents used to prevent infection. In the spring of 2004, U.S. military casualties who presented to the 31st Combat Support Hospital in Baghdad, Iraq, with acute traumatic injuries resulting in open wounds underwent aerobic culture of their wounds to identify the bacteria colonizing the wounds. Forty-nine casualties with 61 separate wounds were evaluated. Wounds were located predominantly in the upper and lower extremities and were primarily from improvised explosive devices or mortars. Thirty wounds (49%) had bacteria recovered on culture, with 40 bacteria identified. Eighteen casualties (20 wounds) had undergone field medical therapy (irrigation and/or antimicrobial treatment); six of these had nine bacterial isolates on culture. Of the 41 wounds from 31 patients who had received no previous therapy, 24 grew 31 bacteria. Gram-positive bacteria (93%), mostly skin-commensal bacteria, were the predominant organisms identified. Only three Gram-negative bacteria were detected, none of which were characterized as broadly resistant to antimicrobial agents. The only resistant bacteria recovered were two isolates of methicillin-resistant *Staphylococcus aureus* (MRSA). Our assessment of war wound bacterioly soon after injury reveals a predominance of Gram-positive organisms of low virulence and pathogenicity. The presence of MRSA in wounds likely reflects the increasing incidence of community-acquired MRSA bacteria. These data suggest that the use of broad-spectrum antibiotics with efficacy against more resistant, Gram-negative bacteria, such as *Pseudomonas aeruginosa* and *Acinetobacter* spp., is unnecessary in early wound management.

Introduction

Infection in war wounds caused great morbidity, and often death, in the preantibiotic era. The bacteriological features of these infections were well recognized, and the evolution of the types of infections and attendant pathogens was well described, although physicians had little in their armamentarium other than debridement with which to treat the patient.[1] The arrival of the antibiotic era radically changed the treatment and prognosis of those wounded in war. Antibiotics began to be used soon after wounding, with the goal of preventing the appearance of infection in the wound. Surprisingly, only one study has characterized the spectrum of bacteria that contaminate the wound immediately after injury (which, if left untreated, would presumably be the organisms to cause later wound infections). That study evaluated cultures collected within a few hours after injury during the Vietnam War, revealing a mixture of bacteria, many presumably nonpathogenic, in the wounds.[2]

We hypothesized that not only susceptible bacteria of less virulence but also occasionally resistant and pathogenic bacteria would be found to contaminate wounds immediately after wounding. In this study, we characterize the bacteriological features of war wounds near the time of injury during the current Iraq conflict. These data may potentially shape the empiric choice of antimicrobial agents to adequately control contamination and to prevent future infection.

Methods

Patient Population

During the spring of 2004, U.S. military casualties who arrived at the 31st Combat Support Hospital (CSH) in Baghdad, Iraq, with an acute traumatic injury resulting in an open wound were evaluated for the presence of bacteria in their wounds. The 31st CSH was a referral hospital for trauma throughout Iraq. Most casualties (n = 31) were directly transported by helicopter from the point of injury to the hospital, arriving within 20 to 40 minutes after injury. A minority of casualties (n = 18) were air-evacuated to the CSH after stabilization by forward deployed physicians, who occasionally irrigated and dressed the wounds, infused antimicrobial agents, or both. Data collected for each casualty included mechanism of injury, previous field medical care (including wound management), antimicrobial use, and location of injury. All major wounds of each casualty were cultured. A minority of patients who arrived did not undergo serial culturing because of mass casualty situations in which an unstable medical condition, requiring rapid resuscitation, precluded adequate sampling. The wounding patterns and previous treatments of these patients were similar to those of patients who underwent culturing when resources were adequate.

Culture Technique

Two culture swabs (BBL CultureSwab Plus collection and transport system for aerobes and anaerobes; Becton Dickinson, Sparks, Maryland) were inserted into the wounds during stabilization in the emergency department and were then directly transported to the laboratory. Swabs were plated onto Columbia blood agar plates, chocolate agar plates, and MacConkey agar plates and into thioglycolate broth for the detection of aerobic bacteria. Blood agar plates and MacConkey agar plates were

*Department of Medicine, Infectious Disease Service, Brooke Army Medical Center, Fort Sam Houston, TX 78234.
†Department of Medicine, Pulmonary and Critical Care Service, William Beaumont Army Medical Center, Fort Bliss, TX 79920.
‡31st Combat Support Hospital, Baghdad, Iraq.

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incubated at 35°C in ambient air and chocolate agar plates in the presence of 5 to 10% CO_2. The thioglycolate broth was Gram-stained if it became turbid. Cultures were held for up to 5 days before results were classified as negative.

Results

Forty-nine casualties with 61 separate wounds were evaluated. Wound sites cultured included 23 head and neck, 17 lower extremity, 15 upper extremity, 5 chest or back, and 1 abdomen. Wounds were caused by gunshots for three casualties (five wound samples), improvised explosive devices for 26 casualties (29 wound samples), mortars for 14 casualties (21 wound samples), and other mechanisms (e.g., rocket-propelled grenade) for six casualties (six wound samples). Tables I and II characterize wound locations and mechanisms of injury for those with and without field therapy, respectively.

Thirty wounds (49%) had the presence of bacteria in cultures taken at the time of initial presentation to the CSH (Tables I and II). Forty different bacteria were identified (Table III). Two organisms were detected in 10 samples and one organism only was found in the remaining 20 samples. Gram-positive organisms (93%) were the predominant organisms identified, with only three Gram-negative bacteria detected. The predominant Gram-positive organisms were overwhelmingly skin-commensal organisms. Two of the *Staphylococcus aureus* isolates were methicillin-resistant *S. aureus* (MRSA). Conspicuously absent were streptococci (especially *Streptococcus pyogenes*). The three Gram-negative bacteria identified were not multidrug resistant.

Eighteen casualties (20 wound samples) underwent field medical care before evacuation and subsequent culture (Table I). Six wounds had the presence of bacteria after field therapy (Table I). Of the wounds treated only with field irrigation (six wounds), none had positive cultures. Wounds treated only with antimicrobial agents (eight wounds) had five positive cultures. Antimicrobial therapy in combination with irrigation was used for six wounds, with one revealing positive culture. Three other wound cultures from patients who underwent field therapy did not grow bacteria, although Gram stains of those cultures revealed Gram-negative rods in one, Gram-positive diplococci in the second, and Gram-positive diplococci with Gram-negative rods in the third. Of the wounds that did not undergo therapy, 24 had the presence of bacteria (Table II). Because of rapid evacuation out of the CSH, no follow-up data were available to compare our microbiological data with eventual outcomes, especially the development of wound infections.

Discussion

Our data characterizing the bacteriological features of war wounds immediately after injury did not support our hypothesis that occasionally resistant and pathogenic bacteria would be found to contaminate wounds immediately after wounding. We found predominance (93%) of Gram-positive organisms, consisting chiefly of skin-commensal pathogens typically considered to be of low virulence and pathogenicity. Resistant Gram-negative bacteria such as *Pseudomonas aeruginosa*, *Klebsiella* spp., and *Acinetobacter* spp. were not recovered. Unique to our data was the detection of MRSA as two of the four *S. aureus* isolates. Although it appears beneficial, we were not able to firmly establish the impact of forward medical therapy with irrigation and/or antimicrobial agents on the colonization rate of war wounds.

The bacteriological features of war wounds are often characterized by the early description by Fleming[1] from 1919. He reported the evolution of infection in war wounds through three phases. The first phase consisted of a watery, foul-smelling, reddish brown discharge attributed to wound bacteria. Organisms typically recovered were sporulating anaerobes (such as *Clostridium* spp.) and streptococci. The second phase occurred ~7 days after wounding, with transition from primarily anaerobic infection to infection with nonsporulating bacteria of fecal origin (e.g., *Escherichia coli* and *Klebsiella* spp.). Wounds were characterized as more purulent but

TABLE I

BACTERIAL WOUND CULTURE RESULTS, ACCORDING TO LOCATION AND MECHANISM OF INJURIES FOR PATIENTS WHO HAD UNDERGONE THERAPY IN THE FIELD BEFORE WOUND CULTURING AT THE CSH

Anatomical Location	Mechanism of Injury (total no.)	No. Irrigation Total	Irrigation Positive Culture	Antimicrobials Total	Antimicrobials Positive Culture	Irrigation and Antimicrobials Total	Irrigation and Antimicrobials Positive Culture
Extremity	IED (4)	2	0	Cefazolin (2)[a]	CNS (1),[a] 2 CNS species (1)[a]	0	0
	Mortar (1)	0	0	Cefazolin (1)[a]	CNS (1)[a]	0	0
	Other (3)	0	0	0	0	Cefazolin (2), ciprofloxacin (1)	0
Head and neck	IED (10)	3	0	Ceftriaxone (1), cefazolin (2),[a] vancomycin (1)	CNS (1)[a]	Ceftriaxone (1), cefazolin (2)[a]	CNS + *Pseudomonas stutzeri* (1)[a,b]
	Mortar (1)	0	0	Cefazolin (1)[a]	CNS + *Micrococcus* (1)[a,b]	0	0
Chest, back, and abdomen	IED (1)	1	0	0	0	0	0
Total	20	6	0	8	5	6	1

IED, improvised explosive device; CNS, coagulase-negative *Staphylococcus* spp. Numbers in parentheses indicate the number of wounds receiving antimicrobial agents or wounds with corresponding bacteria.

[a] Bacteria found with the use of the corresponding antimicrobial agent.

[b] Both found in the same wound culture.

TABLE II

BACTERIAL WOUND CULTURE RESULTS, ACCORDING TO LOCATION AND MECHANISM OF INJURIES, FOR PATIENTS WHO HAD NOT UNDERGONE THERAPY BEFORE WOUND CULTURING AT THE CSH

Anatomical Location	Mechanism of Injury	No. Total	No. Positive Culture
Extremity	Gunshot	2	0
	IED	9	3 CNS, 1 MRSA
	Mortar	12	7 CNS, 1 *Staphylococcus aureus*, 2 CNS + CNS[a]
	Other	1	1 MRSA + *Chryseobacterium meningosepticum*[a]
Head and neck	Gunshot	2	1 CNS
	IED	4	1 CNS + CNS,[a] 1 *S. aureus* + *Escherichia coli*[a]
	Mortar	4	1 CNS, 1 CNS + CNS[a]
	Other	2	1 CNS, 1 CNS + CNS[a]
Chest, back, and abdomen	Gunshot	1	1 CNS
	IED	1	0
	Mortar	3	1 CNS
Total		41	24

IED, improvised explosive device; CNS, coagulase-negative *Staphylococcus* spp.; MRSA, methicillin-resistant *S. aureus*. Numbers preceding bacteria indicate the number of cultures with corresponding bacteria.

[a] Both found in the same wound culture.

TABLE III

BACTERIA CULTURED IN WAR WOUNDS FROM 49 CASUALTIES (61 WOUNDS)

Gram-Positive Bacteria	No.	Gram-Negative Bacteria	No.
Coagulase-negative *Staphylococcus*	32	*Pseudomonas stutzeri*	1
Staphylococcus epidermidis	12	*Chryseobacterium meningosepticum*	1
Staphylococcus auricularis	10	*Escherichia coli*	1
Staphylococcus hominis hominis	6		
Staphylococcus warneri	2		
Staphylococcus cohnii cohnii	1		
Staphylococcus saprophyticus	1		
Staphylococcus aureus	4[a]		
Micrococcus sp.	1		

[a] Two isolates were MRSA.

such drainage then diminished progressively over 2 to 3 weeks. The third phase was a prolonged period with persistent proliferation of pyogenic organisms and resolution of fecal organisms. Representative bacteria in this third phase included *Staphylococcus* spp. and *S. pyogenes*.

Modern surgical management of wounds, focusing on aggressive debridement, likely led to the essential disappearance of clostridial gas gangrene between World War I and the Korean War. Implementation of penicillin use after wounding during World War II probably led to the diminution of *S. pyogenes* infection, because this species remains universally susceptible to this agent. The more recent expanded use and broader spectra of antimicrobial agents occurred simultaneously with the appearance of increasingly resistant bacteria in war wounds.[3,4] These organisms include multidrug-resistant *P. aeruginosa*, extended-spectrum β-lactamase-producing *Klebsiella* spp., and *Acinetobacter* spp., all of which have appeared in war wounds incurred during Operation Iraqi Freedom and Operation Enduring Freedom.[5] These bacteria appear to colonize wounds during definitive care in hospitals.

Early wound culture data are limited to one study performed by Tong,[2] describing the bacteria cultured from 63 wounds of 30 injured U.S. Marines in Vietnam. Casualties presented within 2.5 hours after injury, with cultures being obtained before initiation of debridement or antimicrobial treatment. Initial culture results revealed a relatively even mixture of Gram-negative and Gram-positive bacteria, with a predominance of *Staphylococcus epidermidis*, *Bacillus subtilis*, Mimeae-Herellea-Bacterium-Alcaligenes (likely the organism now known as *Acinetobacter*), and *Enterobacter* group. Cultures obtained 5 days after surgical therapy and implementation of antimicrobial treatment (typically penicillin with streptomycin sulfate, chloramphenicol sodium succinate, or colistin) revealed that 84% of wounds grew Gram-negative bacteria. *S. epidermidis* decreased from 24% of bacterial isolates on day 1 to 5% of isolates on day 5. In contrast, *P. aeruginosa* increased from 2% of bacterial isolates to 29% of isolates between days 1 and 5.

Bacterial contamination of war wounds occurs either at the time of injury or secondary to contamination during the course of therapy.[6] The utility of antimicrobial agents in the management of war wounds soon after an injury is supported by animal and human studies, especially if debridement is delayed.[7,8] However, antibiotics may influence wound flora, selecting more resistant bacteria, a risk that remains unproven.[4] One current controversy that is yet unresolved is the identification of the ideal antibiotic(s) for use in war wound prophylaxis. Randomized prospective studies assessing various treatment strategies would be the ideal means to determine the role of antimicrobial agents in casualty wound prophylaxis. Questions to be addressed would include whether therapy should be narrow or broad in spectrum of activity and how long therapy should continue, or even whether such prophylactic antimicrobial therapy is clearly beneficial at all. Given the circumstances surrounding the care of war wounds, controlled studies have not occurred and are unlikely to be performed in the future.

Antimicrobial agents that were proposed for tactical combat casualty care by one U.S. Special Operations group include gatifloxacin for patients with extremity wounds and cefotetan for patients with abdominal injuries, unconscious patients, and patients in shock.[9] The International Committee of the Red Cross has recommended penicillin for compound fractures, amputations, or major soft tissue wounds.[10] If the injury is associated with land mines or therapy is delayed for 72 hours, then penicillin used in combination with metronidazole is suggested. Our data support a potential need for adequate Gram-positive coverage in acute wounds but do not suggest that broader coverage against resistant Gram-negative bacteria needs to be provided immediately after wounding. The only resistant bacteria we noted were rare MRSA isolates. The presence of war wound MRSA is not unexpected, given the increasing prevalence of community-acquired MRSA, which is a known skin colonizer and thus is likely introduced into wounds at the time of trauma.[11] Approximately 4% of wounded soldiers had MRSA in wound cultures, which approximates the 3% colonization rate described among active duty soldiers.[11] Our data do not suggest that the Gram-negative bacilli recognized in wounds during recent conflicts (Vietnam, Somalia, and Iraq) are inoculated at the time of injury.[2,5,12] Instead, it is more probable that these organisms gain access to open wounds through contact with medical care, through mechanisms similar to those seen in civilian institutions.

This study has limitations. The data are limited by potential sampling bias attributable to the admittedly limited number of casualties and wounds assessed. In addition, the use of culture swabs might not have detected all of the bacteria in the wounds as thoroughly as tissue samples would. However, given the size of the wounds, random small tissue samples also might have missed the presence of bacteria. Anaerobic cultures were not obtained, but anaerobic bacteria have been uncommonly recognized as a cause of war wound infections since rapid evacuation and debridement have become normal practice (approximately since the Korean War). In addition, these samples were obtained in one area of the world and may not represent other regions with different ecosystems and bacteria. An additional limitation was the inability to standardize treatment protocols before wound culture. Finally, because this was not a longitudinal study, we were unable to characterize the development of infection later in these casualties' courses. However, the bacteria initially colonizing wounds at the time of injury are the probable (at least the first) organisms that should be eradicated by early wound management, to prevent the later development of infection.

In summary, war wound cultures obtained immediately after injury during the current Iraq conflict showed the presence of a range of less pathogenic, Gram-positive, skin-commensal bacteria. Gram-negative bacteria were rarely found in wounds at the time of initial injury, and none was multidrug resistant. Similarly, MRSA was uncommonly found in wounds. These data emphasize the need for effective infection-control practices, to prevent nosocomial transmission of resistant bacteria such as *P. aeruginosa*, *Klebsiella pneumonia*, and *Acinetobacter* spp. into wounds. These data also suggest that the use of broad-spectrum antibiotics is unnecessary in early wound management, if indeed colonization (with possible subsequent infection) with resistant organisms does not occur until after contact with medical care.

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